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Neutron tomographic analysis: Material characterization of silver and electrum coins from the 6th and 5th centuries BCE

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ABSTRACT

Neutron tomography was applied to study a set of Greek silver coins and a single Lydian electrum coin minted in the 6 and 5th centuries BCE. The investigation was conducted at the new neutron imaging station DINGO at ANSTO in order to demonstrate capabilities and to explore limits of this non-invasive method in characterizing numismatic materials. From the reconstructed volume of each sample, the morphology, porosity, inclusions, and presence of composite structures can be revealed and evaluated. This information can be used to elucidate ancient minting technology and to prove authenticity. Moreover, the state of conservation, corrosion processes and attempts to repair the coins can be determined.

1. Introduction

In the last decades neutron methods have been established as a powerful non-destructive approach in the field of cultural heritage and conservation science. Typical applications include the investigation of ancient manufacturing processes, material characterization, provenience and authentication study and evaluation of conservation methods [1–4]. The range of materials that can be investigated is broad, but the emphasis has been on pottery and metals. Neutron imaging and diffraction have also attracted the interest of numismatists [5]. In comparison to X-ray, neutrons feature a different contrast mechanism in the interaction with matter. The neutron attenuation coefficient is high for hydrogen and thus for organic materials, while a good transmittance is typical for most metals. These characteristics make neutron techniques, imaging in particular, the ideal tool to study the interior of ancient metal artefacts which require a non-invasive investigation approach. Thanks to the high penetration power of probing particles, neutron imaging can provide a unique insight, at a microscopic scale, into the bulk of dense materials, such as the metal of coins, that are not easily available for x-ray tomography. Neutrons can pass through tens of millimetres of metal materials, while X-rays are generally absorbed within 1–2 mm. This is especially critical for heavy coin metals like silver and gold, where neutrons seem to be the only possibility for tomography.

Morphology, porosity and inclusions can be investigated by means of neutron tomography. It is possible through this technique to detect the features of composite structures. In the study of coins, this information can be related to the method of minting and, consequently, used to prove authenticity. Furthermore, the state of conservation (and attempts at repairs) can be determined through detection of the alteration products which often contrast with the parent material. This analysis can be complemented by the study of neutron diffraction that can determine exact species of the alteration products or reveal features regarding polycrystalline microstructure [6].

In 2014 researchers from the Australian Nuclear Science and Technology Organisation (ANSTO) and the Australian Centre for Ancient Numismatic Studies (ACANS) at Macquarie University launched a program to study the techniques of minting the so-called 'incuse coinage' struck by Greek cities in Southern Italy during the 6th and 5th centuries BCE [7].

In this paper we report results of the neutron tomographic analysis of silver coins obtained on the neutron imaging station DINGO at the Australian Nuclear Science and Technology Organisation (ANSTO) with a focus on the demonstration of how neutron tomography can be used as means of exploring various aspects of ancient minting technology. For this purpose we have selected from the collection some eight silver coins (mostly from South Italy) and a single Lydian electrum coin.

In addition to neutron tomography, texture analysis was performed on the neutron strain scanner KOWARI [8] at OPAL. Assistance was also obtained from the High Resolution Powder Diffractometer ECHIDNA [9]. By investigating the orientation of the polycrystalline structure of the samples, this study will provide a more in depth understanding of

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Table 1
Coins studied on DINGO.

Sample	*Sylloge Nummorum Graecorum, Australia* 1/ACANS inventory numbers	Incuse	Mint city	Mint Date	Weight (g)	Diameter (mm)
1	SNG 526	Yes	Metapontum	c. 540–510 BCE	7.94	22.7
2	SNG 527	Yes	Metapontum	c. 510–470 BCE	8.07	24.3
3	SNG 525	Yes	Metapontum	c. 550–510 BCE	7.43	29
4	SNG 1045	Yes	Croton	c. 510 BCE	8.04	19.8
5	14A07	No	Athens	c. 500–480 BCE	19.8	~17
6	SNG 730	Yes	Sybaris	c. 550–510 BCE	7.73	29.6
7	SNG 729	Yes	Sirinos/Pyxoes	c. 540–510 BCE	6.73	29.6
8	14A09	No	Athens	c. 550–510 BCE	6.72	24
9	15A15	No	Lydia-electrum	c. 600–550 BCE	0.87	~8

different methods of minting. While some diffraction results are brought to complement the tomographic data. The results obtained from neutron diffraction and texture measurements will be reported in full and discussed more extensively in a dedicated paper.

2. Historical information on coin production and plating in the ancient Greek world

Coinage was invented in the Asia Minor kingdom of Lydia in modern Turkey perhaps around 630–620 BCE. The first coins were made of electrum, a gold-silver alloy. According to Herodotus (I.94), the Lydians under their last king, Croesus, changed to a bimetallic system of separate gold and silver coins prior to 546 BCE [10–13]. The practice of minting coins was an innovation transmitted to Greek communities during the 6th century BC through contact with the Lydian Empire [10–16]. It was not until 550–540 BCE, however, that Greek cities in the Aegean (Siphnos, Naxos), around the mainland (Aegina), and in the west (Metapontum, Sybaris) began minting limited issues of silver coins [17–22]. The momentum for striking silver coinage in the Greek world did not become significant until around 530–520 BCE. Gold and silver coinages were used for payments of high value (such as the hire of mercenaries, or the purchase of significant quantities of food). It was not until the invention of a fiduciary coinage in bronze, around 450–440 BCE, that we see the production of mass petty currency and the monetization of more basic common market exchanges.

Greek colonies in Southern Italy, many of them mercantile centres, developed their own method of minting, the so-called incuse coin technique, around the mid-6th century BCE (Table 1; sample 1–4, 6–7) [7]. Here the image on one side of the coin is repeated on the other side in reverse (or intaglio) – and the alignment is always extremely close. While the production techniques for the coinage minted by the majority of Greek cities on the mainland and in Asia Minor are relatively well understood and involved the striking of coins from blanks that had been cast [23], the incuse method developed by cities in South Italy is still unclear.

Metallurgical studies have shed new light on the ancient processes of minting. Plated coins are of particular interest. Here a thin surface layer of precious metal conceals a thick, base metal core (copper, tin or lead). Such coins are commonly interpreted as ancient or modern forgeries [24–27]. In his 1975 study of a hoard of plated Iranian dirhams, Cope [24,28] proposed that ancient forgers dipped the base-metal core into a silver-chloride emulsion in order to achieve their silver appearance [29]. Recent experiments using non-destructive methods of surface and bulk analysis, however, do not support the 'dipping' hypothesis. X-ray- and neutron-based studies indicate that ancient artisans commonly employed thin foils and amalgam pastes to plate coins [28,29]. The metallurgists who plated coins needed a high degree of skill to undertake this work and an intimate knowledge of chemical processes. It is important to note at this point that numismatists are no longer convinced that all ancient plated coins should be considered as forgeries [30–34]. It seems highly likely that states under pressure to produce coinage in excess of their precious metal supplies deliberately minted plated coins to cover the short-fall in gold or silver.

3. Samples

A set of 8 silver coins from the incuse coinage study project of ACANS/ANSTO and one electrum coin minted during the 6th and 5th centuries BCE. were selected for this discussion (Table 1). The silver coins belong to Metapontum, Croton, Sirinos/Pyxoes and Sybaris (all in Southern Italy), and from Athens. The electrum coin (sample No. 9) came from the Lydia in Asia Minor. The variety of origin and mint dates was intentionally chosen to better explore the capabilities of neutron tomography applied to archaeometallurgy and specifically for numismatic materials.

This set of samples of various origin and mint dates was intentionally chosen to test capabilities and limits of the method in term of accuracy and sensitivity for the detection and quantification of key structural features related to different minting techniques.

4. Instrument and experimental set-up

The neutron tomography analysis was performed on DINGO, the ANSTO neutron imaging instrument located on a thermal beam tangentially facing the 20 MW OPAL research reactor in Sydney [35].

Major applications of the instrument fall in the field of industrial processing, geoscience, palaeontology and civil engineering. Being a non-destructive method, neutron imaging is a valuable method to investigate ancient objects as demonstrated by successful studies conducted on other facilities: ICON [36] and NEUTRA [2] at PSI (CH),

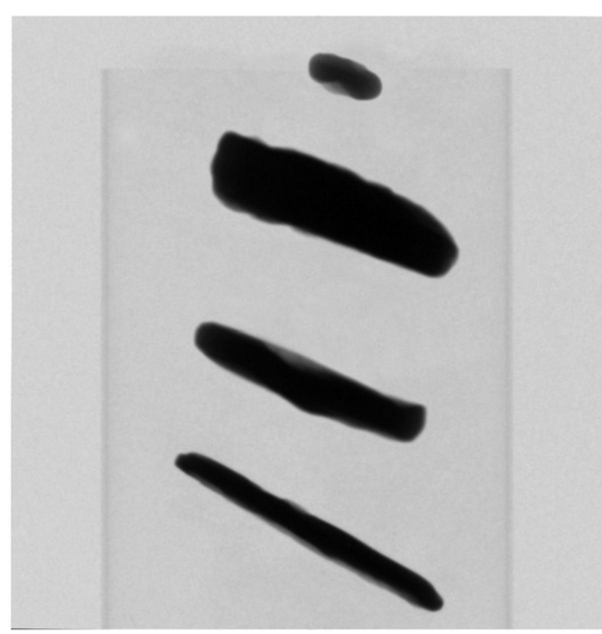

Fig. 1. Neutron radiography showing the arrangement of samples during the tomographic scan.